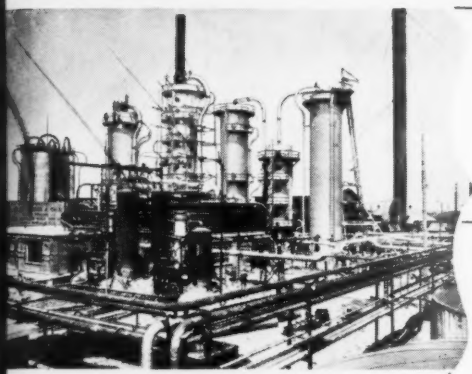
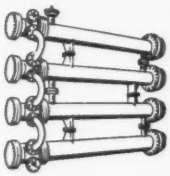
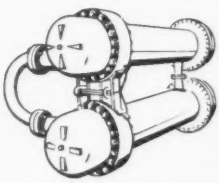
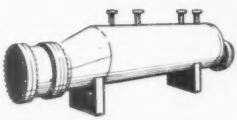
INSTITUTE OF PETROLEUM REVIEW

Vol. 5. No. 54. JUNE 1951. Price 1/6d. Annual Subscription: Fifteen Shilling









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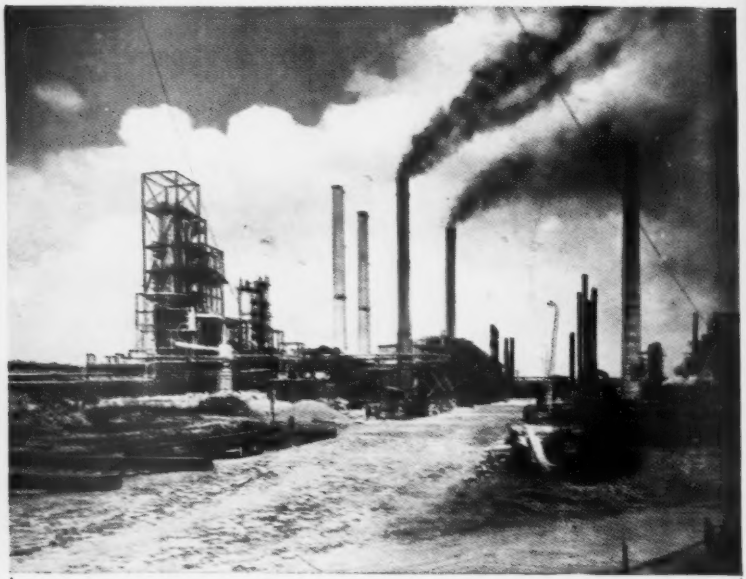

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No. 54 JUNE, 1951 Vol. 5

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SOURCES OF SULPHUR

By C. M. CAWLEY (Fellow)*

INTRODUCTION

The shortage of natural sulphur which is now being felt acutely in Great Britain and throughout the western world, has emphasized the great importance of this raw material to every highly industrialized country. The element sulphur has many uses, such as for example the vulcanization of rubber and the manufacture of the carbon disulphide used in the rayon industry, but its major use is for the production of sulphuric acid, which probably accounts for 75 per cent of the world's consumption of natural sulphur. In addition, sulphuric acid is also made from (1) pyrites, (2) hydrogen sulphide recovered as such or as iron sulphide ("spent oxide") from natural gas, refinery gas and coal gas, (3) smelter gases, and (4) anhydrite.

Sulphuric acid is used in the manufacture of fertilizers and chemicals of all kinds, in oil refining and the metallurgical industries. In fact there is hardly an industry which does not make some use of sulphuric acid, and the consumption of this material is consequently an index of the degree of industrial development in a country. It is not surprising therefore to find that the consumption of sulphuric acid is increasing all over the world; this trend is illustrated by the following data for the United Kingdom.[1]

*Fuel Research Station, Department of Scientific and Industrial Research.

Annual U.K.Consumption of Sulphuric Acid

	Tons
1946	1,397,364
1948	1,613,208
1950	1,816,134

The present situation, in which many countries are facing the possibility of a severe restriction in industrial activity because of the shortage of sulphur, is therefore due essentially to a steadily increasing demand being made on a limited supply. It may be that the difficulty has been accentuated by stockpiling in America, but the shortage is not basically due to any such temporary activity. It follows that although Britain's problem may be eased by an increase in the allocation of sulphur she obtains from the United States, the easement obtained in this way can only be temporary. The permanent solution must be to increase, where possible, the supplies of sulphur from known sources, and to find new sources. It is therefore of interest in this article to review the existing sources of supply.

This article is not primarily concerned with the uses of sulphur. It must, however, be observed that although sulphuric acid is used in a great variety of processes, sulphur often does not appear in the final product. There are many examples of this, but one of particular interest is the rayon in the manufacture of which both carbon disulphide and sulphuric acid are used. Large quantities of sulphuric acid (over 38 per cent of the total consumed in the United Kingdom in 1950) are also used in the manufacture of fertilizers; here sulphur is retained in the product, but serves no useful purpose in the soil in this country since the soils are not deficient in sulphur. Great interest therefore attaches to the possibility of making fertilizers by processes in which sulphuric acid is not required. It is thus apparent that there is considerable scope for processes of recovery and economies in the use of sulphur, which may make a great contribution to the easing of present difficulties, but this is an aspect of the problem which is outside the scope of this article.

Forms of Occurrence of Sulphur

Sulphur occurs in the free state as natural sulphur or brimstone. In the combined state it occurs in various forms of which the most important are (1) metallic sulphides, especially those of iron, copper, zinc and lead, (2) sulphates, especially gypsum, $CaSO_4.2H_2O$, and anhydrite, $CaSO_4$, and (3) various organic sulphur compounds in petroleum and coal.

Sulphur is not abundantly present in the earth's crust, but if the combined sulphur could be made readily available, the supply would be ample for man's use. The dominant fact of the sulphur supply situation, however, is that although natural sulphur is a relatively rare material it has in recent years provided more than half of the world's supply of sulphur.

Natural Sulphur

The most important sources of natural sulphur in the world are in America; they are the salt dome deposits of the Gulf coast region of Texas and Louisiana.[2] The sulphur occurs, usually in a concentration of 20 to 40 per cent, as crystal aggregates in limestone. It is won by the Frasch process which employs hot water to melt the sulphur underground, and it is then raised to the surface by an air lift.

In 1944, the reserves of natural sulphur in this region were estimated to be 80,000,000 tons,[3] and since then about a third of that quantity has been produced. A large part of these reserves is found in two large deposits, the Boling Dome and the Grand Ecaille Dome, and the likelihood of any new deposits of the same magnitude being discovered does not seem to be very great. There has been some speculation about the salt domes in the Gulf of Mexico off the coast of Texas and Louisiana; some of

these may contain sulphur, but the winning of it, though feasible, would in any case be costly.[4] There are also salt domes elsewhere in America and the rest of the world but none offers any great prospects of yielding sulphur in large quantities. The reserves which may be made available in the future in the Western States of America amount to only 2,000,000 tons.[3]

While the reserves of natural sulphur in the United States decline, the annual production continues to mount, as the following figures show.[5]

Production of Natural Sulphur in U.S.A.

Tons

	Production	*Exports*	*U.S. Consumption*
1935-39 (average)	2,175,000	566,000	1,420,000
1946	3,860,000	1,189,000	2,939,000
1948	4,869,000	1,263,000	3,716,000

In this situation therefore it is not surprising that America has begun to grow concerned about the conservation of its natural resources.

Natural sulphur is found in other parts of the world but production is relatively small. Thus mines of great antiquity are still worked in Sicily and Italy. Underground mining methods are used and the sulphur is recovered by a process which employs the heat of combustion of part of the sulphur to liquefy or vaporize the remainder. The sulphur in consequence is much more costly than that obtained by the Frasch process. The production from these deposits was about 170,000 tons in 1948.[5]

Smaller quantities are produced to meet local needs in several other countries, but the total world output in 1948 (5,300,000 tons) was only 6 per cent more than the U.S. output.

Pyrites

Natural sulphur and pyrites together contribute the great bulk of the world's supply of sulphur. The trend in the production of pyrites in recent years is indicated by the following figures.[5]

World Production of Pyrites (including Copper Pyrites

Tons

	Gross Production	*Sulphur Content*
1938	11,000,000	4,700,000
1946	7,000,000	3,000,000
1948	9,000,000	3,800,000

It is evident from a comparison of the data in the two foregoing tables that the contribution from pyrites was much greater than that from natural sulphur in 1938, though the positions are reversed today. The production of pyrites fell off during the war years, but it is now rising rapidly, and it seems likely that the proportional contribution from natural sulphur will diminish steadily, albeit slowly, from now onwards.

The production of pyrites is also increasing in the United States—

U.S. Production of Pyrites

Tons

1944	788,530
1946	813,372
1948	928,531

but this material accounts for only a relatively small part of the nation's supply, mainly because of the low cost of natural sulphur obtained by the Frasch process. In Europe on the other hand, pyrites provides the major supply of sulphur. Europe holds the world's largest reserve of pyrites; this is located in the southern part of Spain and in Portugal, and is estimated at 500,000,000 tons, equivalent to more than 200,000,000 tons of sulphur.[2] Pyrites deposits of commercial size, however, are found in many other parts of Europe and throughout the world.

Pyrites often occurs as "coal pyrites" in association with coal. Although the proportion is small, the quantity available from this source is potentially very great because of the vastness of the world's coal reserves. The recovery of coal pyrites is, however, troublesome and costly, and in consequence there is little production anywhere. In Britain during the war a great effort gave an annual yield of only 50,000 tons, and this has now fallen to 20,000 tons.

Smelter Gases

All other supplies of sulphur are relatively small, though considerable; they are of particular importance in countries in which natural sulphur has not been readily available, and their importance is growing throughout the world. Most of these supplies are obtained as by-products from the metallurgical and fuel industries, though a small quantity is obtained from natural sulphates (anhydrite).

The smelting of certain metals, particularly zinc, lead and copper, which occur in nature as sulphides, yields gases rich in sulphur dioxide during the initial roasting process. The production of sulphuric acid from smelter gases has in consequence been practised for a very long time, especially in Britain and Europe. Thus in Britain the gases from the roasting of zinc concentrates, obtained from the separation of lead and zinc ores, provide about 10 per cent of the nation's supply of sulphuric acid (see Table II).

There is, however, considerable scope for the greater recovery of sulphur from smelter gases in America, and the following estimates (Table I) have been made[6] of the quantities of sulphur, as sulphur dioxide, emitted to the atmosphere from the roasting of sulphide ores and the combustion of coal and oil (the hydrogen sulphide from natural gas and petroleum is also included).

Table I

Estimated Sulphur Emitted to Atmosphere Annually[6]
Metric tons

Year	1943	1946
Zinc plant.....	1,462,000	1,123,000
Lead smelters.....	252,000	187,000
Copper smelters ..	5,512,000	3,670,000
Nickel smelters ...	1,238,000	749,000
Crude oil	4,513,000	5,500,000
Coal	25,700,000	—

Coal

The estimated quantity of sulphur (Table I) emitted to the atmosphere from the burning of coal is enormous, and greatly exceeds the world production of usable sulphur. In Britain alone, where the coal produced has an average sulphur content of 1.5 per cent, 5,000,000 tons of sulphur dioxide are emitted to the atmosphere every year, and most of this is virtually irrecoverable.

This pollution of the atmosphere has of course been a matter of grave concern for a very long time, and much attention has been given to processes for the removal of sulphur dioxide from the flue gases from power stations. There are several objections to the use of such processes, not the least of which is their great cost, but with the rise in the price of sulphur which has already started and which is bound to continue in the future, the economics of certain flue-gas washing processes will be considerably modified.

The removal of sulphur dioxide from flue gases has already been practised at the power stations at Battersea and Fulham. At Battersea the flue gases are scrubbed with Thames water containing a little chalk, and the disadvantages of the process, apart from the cost, are the large amount of water used (35 tons per ton of coal burned) and the discharge of calcium sulphate into the river. At Fulham, the process used before the war consisted in scrubbing the flue gases with a suspension of lime or chalk in water. It was more expensive than the Battersea process and necessitated the disposal of a valueless sludge of calcium sulphate.

A third process, devised before the war by the Fulham Power Station authorities and Simon-Carves Ltd., employs as the scrubbing agent an aqueous solution of ammonium salts to which ammonia is added, either as pure ammonia or ammoniacal liquor from gasworks. This process is now under examination on the pilot scale at the Fuel Research Station. An attractive feature is that the sulphur is

recovered as ammonium sulphate, but it does not appear at present that the economics of the process will be any more favourable than those of the Battersea process.

Hydrogen Sulphide

The carbonization of coal at gasworks yields a gas which before purification usually contains about 500 grains per 100 cu. ft. of hydrogen sulphide (i.e. about 0.8 per cent) and the removal of this contaminant is compulsory when the gas is to be distributed for town use. Various processes are available for this purpose but the iron oxide process is almost universally employed. The gas, with sufficient air to provide about 0.5 to 1.0 per cent of oxygen, is passed through iron oxide and the net chemical reaction is—

$$2\,H_2S + O_2 = 2S + 2\,H_2O$$

The process is continued until the iron oxide mass contains about 50 per cent of sulphur.

The resulting "spent oxide" is sold to sulphuric acid manufacturers at a price which is determined by the current price for iron pyrites; it is not sufficient to cover the cost of the purification treatment, a considerable part of which is in consequence borne by the gas. In Britain, spent oxide provides the raw material for nearly 20 per cent of the sulphuric acid made (see Table II).

Nearly as much coal is carbonized in Britain at coke ovens as at gasworks (23 as against 25 million tons in 1949), and the hydrogen sulphide contents of the gases are similar. Some of the coke-oven gas is sold to gasworks for distribution as town gas and is accordingly freed from hydrogen sulphide, but the major part is used without purification for heating the coke ovens or for other industrial purposes. There is therefore in coke-oven gas a potential source of a considerable quantity of sulphur, but the fact that the sulphur recovered will not pay for the purification treatment presents an economic difficulty.

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Hydrogen sulphide is present to different extents both in natural gas and the gas held in solution in petroleum under the conditions of temperature and pressure obtaining in the oil reservoirs. The hydrogen sulphide content of the gas ranges from a negligible quantity up to about 7 per cent. The world's reserve of sulphur in this form is very great, and it is all potentially recoverable, but since it is available only as a

TABLE II

Raw Materials Used for Sulphuric Acid Production in the United Kingdom

	1938	1946	1948	1950
Total production of sulphuric acid, tons[1]	994,000	1,379,194	1,601,438	1,802,699
Raw Materials used in the Production of Sulphuric Acid, tons[2]:—				
Sulphur and H_2S	74,500	202,051	267,003	357,675
Spent oxide	146,200	191,346	197,758	194,447
Zinc concentrates	141,600	163,195	149,321	176,365
Pyrites	364,400	312,697	336,758	204,987
Anhydrite*				184,807
Proportion of Total Sulphuric Acid Contributed by Raw Materials, per cent (approx):—				
Sulphur and H_2S	21	44	50	55
Spent oxide	20	21	19	15
Zinc concentrates	12	11	8	8
Pyrites	47	24	23	16
Anhydrite				6

*Included as "converted" to pyrites.

by-product, the rate of recovery is determined by the rate of oil and gas production. Furthermore, in the past, much of the hydrogen sulphide was not removed from the gas, and much that was removed was burnt in flares. Since the oil industry uses large quantities of sulphuric acid, it is doubtful whether the industry has been a net producer of sulphur of any great importance, but this position is changing rapidly, especially in America where most of the hydrogen sulphide not at present recovered is available.

A much larger quantity of sulphur is present as organic sulphur compounds in petroleum, the sulphur content of which may have almost any value up to about 2½ per cent, and in a few instances may be considerably higher. When crude petroleum is distilled, some degradation of the sulphur compounds occurs, but about 80-90 per cent of the sulphur remains in the residual fuel oil. A small though important quantity becomes available as hydrogen sulphide as a result of cracking operations, and a large and increasing proportion of this sulphur is being recovered.

There are many methods of recovering hydrogen sulphide from natural gas and refinery gas, but the most widely used is the Girbotol process in which the gases are scrubbed with an absorbent for hydrogen sulphide which is afterwards recovered by steaming. The absorbent is essentially an aqueous solution of mono- or di-ethanolamine.

It is doubtful whether much more sulphur from these sources can be made available to supplement British supplies, but in America the oil industry will become an increasingly important producer of sulphuric acid.

The bulk of the sulphur in petroleum is not at present recoverable. Residual fuel oil would provide the richest source of sulphur, but this could only be made available as a by-product of hydrogenation; the use of this process would only be justified as a means of producing higher-grade oils, and even for this purpose it is at present quite uneconomic.

Anhydrite

Processes for the production of sulphuric acid from natural sulphates are available and are being operated in Britain and Europe. Since deposits of gypsum and anhydrite are rich and widespread throughout the world, they provide a potential source of very large quantities of sulphuric acid. Only limited quantities, however, are in fact being manufactured, mainly because of the high capital cost of the plant required—about five to six times as much as for plant producing acid from natural sulphur.[7]

Heavy transport charges on the raw materials make it desirable to locate the plant near the deposit. One of Britain's richest deposits of anhydrite is found at Billingham, which is also the site of the plant of Imperial Chemical Industries Ltd.—the largest plant of its kind in the world—for making sulphuric acid from anhydrite. The annual production amounts to about six per cent of the country's supply (see Table II).

The process makes use of the reaction which occurs when calcium sulphate is roasted in the presence of coke—

$$CaSO_4 + C = CaO + SO_2 + CO$$

In practice anhydrite is intimately mixed with sand, coke, and ashes containing alumina, and the mixture is heated in a rotary kiln to a final temperature of 1,400 C. The lime combines with silica and alumina to yield cement clinker, and the sulphur dioxide evolved is converted to sulphuric acid in a contact plant. One ton of anhydrite yields about 0.6 ton of clinker and 0.6 ton of acid.[10]

The economics of the process depend very much on the price obtained for the cement clinker, and this factor may limit the extent to which the manufacture of sulphuric acid in this way can

be expanded. Nevertheless, the process has obvious attractions, and it was recently reported[7] that the British Government has approved the erection of a new plant to produce about 150,000 tons of sulphuric acid a year from anhydrite. It is expected that the plant will cost about £3,500,000 and will take at least two years to build.[7]

Other Processes

Reference has now been made to all the major methods which are at present being used, or are likely to be used, for the production of sulphur. One other method of an entirely different kind must however be mentioned. This is the micro-biological production of sulphur by the action of sulphate-reducing bacteria.[9] It is known that sulphur can be produced in this way and that it takes place on a large scale in nature, for example, in some sulphur-producing lakes in Cyrenaica. The chief obstacle to the industrial exploitation of the process is the low specific rate of reduction of sulphates; to make the process economically feasible it would be necessary to obtain strains of bacteria able to reduce sulphates at a rate about ten times greater than the normal. Research on possible ways of speeding up the rate is proceeding at the Chemical Research Laboratory. A commercial process is, however, not yet within sight.

U.K. Supplies

The quantity of natural sulphur imported into the United Kingdom has increased more than threefold since 1938 as the data in Table III show[8]. The consumption of sulphur was still rising in 1950, and the full import requirements for 1951 were officially estimated at 460,000 tons.[7] This was the situation when the United States Government, faced by a rapidly increasing consumption of sulphur at home, decided that it must conserve U.S. resources by diminishing exports. Britain's allocation of sulphur during the first quarter of 1951 became 81,000 tons, and consequently consumption in this country suffered an immediate cut of 30 per cent. Later in the first quarter of the year, Britain received an additional 19,000 tons, and an allocation of 95,000 tons was made for the second quarter; the reduction in supplies for the first six months of 1951 was therefore not so great as had at one time been feared. It is evident, however, that exports of sulphur from America will sooner or later be more drastically reduced, and it is urgently necessary for alternative sources of supply to be established.

The quantities of raw materials used in the United Kingdom for sulphuric acid production before the war and in recent years are given in Table II. They show, first of all, the great increase in sulphuric acid production which has taken place since 1938. They also show that a great change has occurred in the relative proportions of pyrites and natural sulphur. Before the war pyrites played the major rôle but the positions are now reversed. The capital cost of plant for making acid from pyrites is about double that of

Table III

U.K. Imports of Natural Sulphur[8]

tons

Source	1938	1946	1948	1949	1950
British Countries	183	—	—	—	—
Italy	21,498	—	—	—	—
U.S.A.	101,819	246,349	348,317	392,369	438,954
Other Foreign Countries	8,028	111	275	555	357
Total	131,528	246,460	348,592	392,924	439,311

plant using sulphur, and since crude sulphur was then freely available the development which occurred was inevitable.

It is now equally inevitable that the consumption of natural sulphur should rapidly decline. Some natural sulphur should be available from Italy but this can only be a very small quantity in relation to Britain's needs. The Italian mines have high costs, the industry is disorganized, and the output is far below pre-war level and will probably take some years to recover.

It might therefore seem to be a natural solution to the problem to return to the position holding before the war when pyrites was the most important source of acid. The reserves of pyrites in Spain are very great, but the output would need considerable expansion to meet Britain's needs and this in turn would require more plant and manpower. Moreover, the plant for making acid from pyrites is not only more costly but it also needs more room, so that conversion from sulphur-using plant might be difficult, at any rate in some cases.

Very similar considerations apply to the greater use of spent oxide. Acid-making plant using spent oxide is similar in cost to that using pyrites, and no additional supplies of spent oxide can be made available without further capital expenditure. The hydrogen sulphide in gas made at gas-works is already completely recovered, and purification of coke-oven gas would require the installation of new plant; as already explained above the spent oxide from this source would moreover be more costly than that at present available.

The sulphur shortage therefore faces British industry with a serious threat and its avoidance will require much ingenuity, effort, time and money. It is natural to ask why this situation should have arisen so suddenly. The fact is that it has existed for some considerable time, and the action of the United States Government, from its own point of view, is belated rather than premature.

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U.K. OIL CONSUMPTION

During 1950 the total quantity of petroleum products released for home consumption on payment of Customs Duty was 12 per cent higher than in the preceding year. All products except "other light oils" and kerosine were made available for consumption in greater quantities, the largest increase being 35.3 per cent for "other heavy oils." Other increases were: motor spirit, 11.7 per cent; lubricating oil, 8.7 per cent; gas oil, 16.7 per cent; road fuel oil, 12.8 per cent; "other" fuel oil, 17.9 per cent. Details are given in the accompanying table.

	1950	1949
	in 1,000 *gallons*	
Motor spirit	1,545,012	1,382,914
Other light oils	52,975	55,289
Kerosine	442,127	465,361
Lubricating oil	188,968	173,906
Gas oil	462,060	395,914
Road fuel oil	250,894	222,349
Other fuel oil	1,570,935	1,332,399
Other heavy oils	16,760	12,391
Total	4,529,732	4,040,523

COUNCIL AND OFFICERS 1951-2

C. A. P. Southwell

At the Annual General Meeting of the Institute on April 26, 1951, the nomination that **Mr C. A. P. Southwell,** M.C., B.Sc., be re-elected as President of the Institute for the Session 1951-52, was unanimously approved.

Thanking the Institute for the honour which had again been conferred upon him, Mr Southwell said that he had every confidence that the Institute could be made of real value to its members and to the industry. It was a worthy public service and he wished to express his appreciation of the support he had had as president from the Council, its officers, and the staff. He wished the members to know that he would use his best endeavours during the coming year to further the interests of the Institute.

Mr C. A. P. Southwell is managing director of the Kuwait Oil Co. Ltd. and previously was manager of the Fields and Geological Branch of the Anglo-Iranian Oil Co. He joined the Institute in 1928, was elected to the Council in 1936, made a vice-president in 1948, and has been a member of various committees of Council.

E. B. Evans

VICE-PRESIDENT

At the same meeting **E. B. Evans,** Ph.D., M.Sc., F.R.I.C., M.Inst.F., was unanimously elected a vice-president.

Dr Evans, who was first elected to the Council in 1939 and was vice-president for the period 1948-50, has been honorary associate editor and deputy chairman of the Publications Committee since 1946. He serves on several other Council committees, was chairman of Standardization Sub-Committee 3 from 1943 to 1948, and a member of and secretary to the Hydrocarbon Research Group from 1944 until 1947.

At present Dr Evans is chief chemist of the Esso Development Co. Ltd., having been research co-ordinator for the same company from 1946 to 1950. From 1926 until the outbreak of war he was a chemist with the Anglo-American Oil Co., Ltd., at the Purfleet installation, at the Vauxhall Laboratories, and in the Technical Sales Department. He was seconded to the Chemical Department of the Petroleum Board at the beginning of the war and returned to "Anglo" in 1945.

Dr Evans has been the author of numerous papers on petroleum matters, many of which have appeared in the *Journal* of the Institute.

COUNCIL

The following were re-elected as members of Council :

W. S. Ault, B.A.

D. L. Samuel, B.Sc., A.R.I.C.

E. J. Sturgess, B.Sc.

O. F. Thompson, O.B.E.

Ex-officio members of Council to represent the Branches were elected as follows :

Fawley Branch: I. McCallum, B.Sc.

London Branch: N. E. F. Hitchcock, B.Sc.

Northern Branch: H. H. Ballard.

Scottish Branch: W. M. Stirling, A.M.I.E.E., M.Inst.F.

South Wales Branch: E. J. Horley.

Stanlow Branch: J. C. Cragg, B.Sc., F.R.I.C.

HONORARY OFFICERS

G. H. Coxon and **C. Chilvers,** B.Sc., F.R.I.C., were unanimously re-elected as honorary treasurer and honorary secretary respectively.

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PERSONAL NOTES

Congratulations to **Prof F. H. Garner,** O.B.E., F.Inst.Pet., on the award to him by the Institute of Fuel of the Melchett Medal for 1951, and on the award to him by the Institution of Chemical Engineers of the Osborne-Reynolds Medal. The latter was awarded in recognition of his work in the sphere of chemical engineering in the Birmingham area and in particular for his work in connexion with the establishment of the Midland Branch of the Institution, of which he is first chairman.

Sir Henry Tizard, G.C.B., A.F.C., F.R.S., has been awarded the Honorary Membership of the Institution of Mining and Metallurgy, in recognition of his outstanding services to science, industry, and education. The same Institution has also awarded Honorary Membership to **Sir Andrew Bryan,** J.P., H.M. Chief Inspector of Mines, in recognition of his distinguished services to the mining industry in the U.K.

V. L. Farthing, M.Inst.Pet., has been elected junior vice-president of the Liverpool Engineering Society and president of the Liverpool Metallurgical Society.

T. W. Mathias

T. W. Mathias, F.Inst.Pet., has been appointed general operations manager of Shell-Mex and B.P. Ltd. Mr Mathias joined Shell-Mex Ltd. in 1922 as a chemist in the company's central laboratories, then at Shell Haven. In 1948 he became manager of the Mexphalte (now Bitumen) dept of Shell-Mex and B.P.

A. R. de Beer

A. R. de Beer, has become manager of the Bitumen department of Shell-Mex and B.P. Ltd. in which capacity he will be assisted by **A. W. Jarman,** M.Inst.Pet., as assistant manager. Mr de Beer has had 28 years service with the company and its predecessors, Shell-Mex Ltd. During the war he was secretary of the Bitumen Pool of the Petroleum Board.

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A.F.T.P.

In our March issue there appeared an article on the organisation and work of the Institut Français du Pétrole, and the inference may have been drawn that the Institut was the exact counterpart in France of the Institute of Petroleum in Britain. In fact, the counterpart of the I.P. is the Association Française des Téchniciens du Pétrole, and it is hoped that at a later date an account of the work of that Association may appear in our columns.

THE PROGRESS OF LABORATORY AND ROAD KNOCK RATING TECHNIQUES*

By C. H. SPRAKE† (Fellow)

General Remarks

A brief review will be given of the more important methods which have been used over the past 30 years or so to evaluate motor fuels in respect to their resistance to detonation. These methods can conveniently be divided into those used in the laboratory and those used in vehicles on the road. The anti-knock value of a fuel is finally determined by its road performance, but the laboratory test methods are evolved with the object of enabling that performance to be predicted.

The tendency of a motor fuel to detonate, more familiarly to "knock" or to "pink", is the factor which perhaps more than any other, limits the power obtainable from an engine, as, in addition to being objectionable, heavy detonation can cause overheating and damage to engine parts and loss of power or total engine failure if allowed to persist. Detonation occurs when the fuel-air mixture burns too rapidly, so causing high local pressures and temperatures within the combustion chamber. Spontaneous ignition of part of the charge then ensues and the resulting high-pressure waves as they strike the walls of the combustion chamber give rise to the familiar noise called knocking.

Prior to the first world war little routine test work was carried out on the anti-knock properties of motor fuels. Gasoline was then sold mainly on volatility specification. Engine compression ratios were low by present standards (some as low as 3½:1) and fuels were of relatively low anti-knock quality, probably mainly between 50 and 60 octane number, which would be quite inadequate for present-day cars.

Immediately after the war great interest was taken in the anti-knock properties of fuels as it was realized that only by increasing resistance to detonation could engine efficiency be improved by the use of higher compression ratios. Ricardo's work at that time on the subject of detonation was outstanding and the results of his investigations commencing in 1919 for the Asiatic Petroleum Company, and for the Empire Fuels Committee in 1920, constituted the bulk of the "Report of the Empire Fuels Committee" which was published in 1924. This dealt with the anti-knock properties of some typical motor fuels, pure hydrocarbons, and alcohol blends.

The work of Midgeley and Boyd in the U.S.A. at about this time, also had a profound effect on the development of motor fuels, the discovery by Midgeley of the high anti-knock properties of tetra-ethyl lead being destined to have far-reaching effects on automotive and aircraft engine design and performance.

Development of Knock-testing Engines

Ricardo's engine, known as the E.35, was a single-cylinder engine of $4\frac{1}{2} \times 8$-inch bore and stroke. The compression ratio could be varied whilst running between 3.7:1 and 8:1. It had two inlet and three exhaust valves, and four spark plugs operated from four coils having their primaries wired in parallel. Normally, however, two plugs only were used. The engine was coupled to an electric dynamometer for loading and measurement of power, and during tests all conditions were closely controlled. The anti-knock properties of

*Paper delivered to the Fawley Branch of the Institute, December 13, 1950.

†Esso Development Co. Ltd.

fuels were measured by determining the highest compression ratio which could be employed before knock became audible with the mixture strength and spark maintained at settings giving maximum power at the speed (generally 1,500 r.p.m.) employed. The compression ratio determined was known as the Highest Useful Compression Ratio (or H.U.C.R.) and was repeatable within very close limits. The term was, however, purely relative to a specific engine operating under specified conditions and the H.U.C.R. of a fuel varied widely on different types of engine or under different operating conditions.

An early engine, built in 1923, was the Thornycroft variable compression engine, of which only three were made. One of these was used by Professor Garner at Fawley, whilst the other two were installed by the Anglo-American Oil Co. and by the Anglo-Iranian at Sunbury.

The Thornycroft engine was about half the size of the E.35 and the test method used was generally the H.U.C.R. method. Around this time also the Anglo-Iranian Oil Company developed the Armstrong variable compression engine. This was a smaller engine of about 370-cc capacity and the compression ratio was varied by a sliding plug, the maximum ratio obtainable being 8:1.

Knock was measured in the earlier methods of test almost entirely by ear and although fairly accurate with trained observers, the invention of the bouncing pin by Midgeley in 1922 proved to be of great importance. With minor modifications, it has remained in use till the present time, although there are now other knock indicators. One in particular, the Phillips detonation meter, may be used at the option of the operator in place of the bouncing pin.

The bouncing pin is a simple apparatus but requires great care in adjustment. Knocking is caused by spontaneous ignition setting up violent high-pressure waves in the combustion chamber. The thin diaphragm at the base of the bouncing pin is exposed in the combustion chamber on its lower side, but the pressure rise during a normal quiet combustion is not sufficiently rapid to cause the pin to leave its seat. When detonation occurs, however, the violent pressure rise rapidly deflects the diaphragm and causes the pin to bounce and close two electric contacts. The upper contact rests on a spring plunger and the time of contact varies with the intensity of the blow delivered by the pin. Thus, the length of time when current flows through the contacts is related to the intensity of detonation and a suitably damped meter indicates in effect the average duration of these electric impulses on a convenient scale, the scale reading becoming higher as detonation increases. This type of knock meter is extremely sensitive and measures differences between knock intensities much too small to be detected by ear.

The use of tetra-ethyl lead as an anti-detonant was first adopted in the U.K. by the Anglo-American Oil Co. when ethyl petrol was introduced in 1927, and at this time the Ethyl Gasoline Corporation introduced the Delco engine for controlling the anti-knock qualities of leaded gasolines. This engine was basically a small lighting set modified by substituting a water-cooled cylinder for the normal air-cooled cylinder. The 400-cc engine was fitted with a simple two-bowl carburettor and means of controlling speed and jacket temperature. Knock was measured by means of the bouncing pin and fuel quality maintained by matching the fuel to be tested against standard reference fuels. The engine compression ratio was fixed and knock was governed by throttle opening. The method was crude by present standards as, initially, no account was taken of the effects of mixture variation.

Early in 1930 the S.30 engine, basically the Delco engine with the loading generator removed, was introduced by the Ethyl Gasoline Corporation. The engine was belt-coupled to a synchronous motor which maintained constant speed at any throttle opening. The jacket temperature was automatically maintained at 212°F by means of a reflux condenser and a much improved three-bowl carburettor with mixture strength control was fitted. Improved ignition equipment was also incorporated with provision for accurate control of the spark timing.

Until this time there were no generally accepted reproducible fuels to serve as a reliable basis for the evaluation of knock and various scales other than the H.U.C.R. were used. Ricardo introduced the "Toluene Value" scale, which expressed the anti-knock properties of a fuel as measured in a variable compression engine from −100 to +100 toluene. This scale bore a straight line relationship with H.U.C.R. and was constructed from two points (0 and +100 on the scale) corresponding to the H.U.C.R. values of an aromatic free spirit used extensively by Ricardo in his work (0 at an H.U.C.R. of 4.85:1) and of toluene (+100 at an H.U.C.R. of 7.8:1) on the E.35 engine. Neither the H.U.C.R. nor the toluene value scales give a straight-line relationship with maximum power output free of knock, but the toluene scale did give an idea of the anti-knock value of a fuel in terms of two known fuels, one extremely good and the other poor (approximately 50 octane). On this scale *n*-heptane (zero octane number) has a toluene value of about −37.

A similar type of knock scale used by the Jersey Company was the S.O.N.J. scale. This was an attempt to rate fuels on an absolute knock basis using batches of reference fuels made up in large quantities in the U.S. and which were more or less reproducible. The scale had a range of approximately 50 to 78.5 octane number on the S.30 engine using a jacket temperature of 212°F. A knock rating of 10 corresponded to the lower and 0 to the higher octane number and intermediate ratings were approximately proportional to the knock developed over a period of time as measured by the bouncing pin, which was connected to an electrolytic cell, the gas generated in one minute being the indication of knock intensity. In practice fuels were run at a constant degree of knock controlled by throttle opening and matched against blends of calibrated sub-standard reference fuels.

During 1929-30 the Waukesha Motor Company in the U.S. were experimenting with a new variable compression engine for knock testing designed by Hofning of that company. The Co-operative Fuel Research Committee of the S.A.E. sponsored this engine and after improvements had been incorporated, the C.F.R. engine was adopted in 1931 and very rapidly became almost universally used for knock-rating tests on automotive and aviation fuels. This engine, with various improvements, has now been the standard test engine for nearly 20 years and is so well known that any further description is perhaps not necessary.

The Octane Scale

The octane scale came into general use in 1931. Dr Graham Edgar first synthesized *iso*octane in quantity in the U.S.A. in 1927 and suggested the use of this hydrocarbon together with normal heptane as standards for the measurement of the anti-knock properties of fuels. The C.F.R. Committee adopted the scale and it was approved by the S.A.E. and recommended for general use four years later.

The cost of both octane and heptane (then £5 per gallon) prohibited their general use except for the calibration of secondary reference fuels, and such

secondary reference fuels were shortly thereafter made generally available by the Standard Oil Development Company, after the calibration of each batch in terms of octane/heptane had been carried out by a large number of laboratories in the U.S.A. During recent years the cost of production of commercially pure octane and heptane has been reduced to such an extent that primary fuels can now be used not only for laboratory tests but if so desired for road tests also.

The advantages of this are obvious as the laborious calibration work necessary in the preparation of each batch of secondary fuel is obviated and road rating can be expressed accurately in terms of primary fuels. This is not possible if secondary fuels only are used, as variations between car engines would entail calibration of secondary fuels in terms of octane/heptane in every vehicle if accurate results in terms of primary fuels were required.

Temperature Sensitivity

An important characteristic of a motor fuel is its sensitivity to engine temperature conditions and this is measured by determining its octane number rating under various sets of engine conditions. Practically all normal types of fuel are more sensitive to changes in operating temperature than are octane/heptane blends and in consequence the octane numbers of normal fuels rise or fall as conditions are made, respectively, less or more severe. Two methods of test are normally employed with the C.F.R. engine to measure this temperature sensitivity, the less severe being known as the Research Method and the more severe as the Motor Method. The Research Method octane number is nearly always higher than its Motor Method number and the difference between the two ratings is the accepted measure of temperature sensitivity.

A brief reference to the origin of these tests methods may be of interest.

Prior to 1932 little road test work on cars had been carried out to establish a relationship between the laboratory rating of fuels and their road performance. Test conditions then used in the laboratory were generally much less severe than the Motor Method conditions, being in fact much closer to the present C.F.R. Research Method.

Manufacturing processes were producing fuels of greater temperature sensitivity than previously and it was realized that correlation between road performance and laboratory ratings was poor. In 1932 a comprehensive programme of road tests was carried out in the U.S.A. at Uniontown, in which a wide selection of fuels was rated in a large number of cars in terms of secondary standard reference fuels, which were straight-run fuels similar in sensitivity characteristics to octane/heptane blends. After these tests an intensive programme of tests was carried out on C.F.R. engines at the works of the Waukesha Motor Co. and a set of test conditions was determined (designated as the Motor Method) which gave the best correlation with the road results. From that time the C.F.R. engine rapidly became almost universally used for the knock testing of motor fuels.

In 1934 further tests were made at Uniontown in which more than 40 representatives of the petroleum industry, car manufacturers, and American Universities took part. These tests confirmed that the Motor Method still gave reasonably good average correlation with road results.

Since then methods of fuel manufacture have still further changed and the tendency is for temperature sensitivity to increase as the anti-knock properties of fuels increase. At present the Research Method octane number of some of the components of motor gasoline may be 15 octane numbers higher than their Motor Method ratings.

It may be of interest to describe the standardized methods of tests for motor fuels a little more fully.

Table I shows the principal operating conditions of these tests, and it will be noted that the main differences are in engine speed, spark timing, and mixture temperature. It has been found that wide variations in the humidity of the atmosphere may affect the octane rating and for this reason the humidity of the air intake has been limited to the range of 25-50 grains of water vapour per pound of dry air. Quite often, and more frequently in the warmer weather, the water vapour content of the atmosphere exceeds 50 grains and it is then necessary to supply air to the engine through a bed of cracked ice. This procedure ensures that the air entering the engine is saturated at a temperature of 32°F and under these conditions the humidity is constant at 28 grains of water vapour per pound of air.

The air is then heated to 100°F or 125°F before entering the carburettor. In the Motor Method the air/fuel mixture is heated further to 300°F between the carburettor and the inlet to the engine.

The compression ratio of the C.F.R. engine can be varied between 4:1 and 10:1 whilst running and the compression ratio which will result in the standard intensity of knock is specified at any barometric pressure for the whole range of octane numbers. When determining the octane number of a fuel its rating can be estimated roughly from the compression ratio found necessary to give this degree of knock as measured by the bouncing pin and knock meter. By trial and error, blends of octane and heptane differing by, say, two octane numbers are then found which knock more and less than the fuel being tested. The compression ratio is then finally adjusted to its correct value for the octane number of the reference fuel blends being used and the octane number of the fuel being tested is interpolated from the knock meter readings obtained on the two blends of reference fuels and the test fuel.

The octane number of fuels determined on the C.F.R. engine should be repeatable on the same engine to within ± 0.5 octane number and the rating of a fuel determined on several engines should not vary by more than ± 1.0 octane number from the mean value.

TABLE I

C.F.R. Engine Test Conditions

	Motor	*Research*
Speed	900 r.p.m.	600 r.p.m.
Jacket temp	212°F	212°F
Spark timing	Varied automatically 26° BTC at 5:1 Comp 24° BTC at 5.5:1 Comp 22° BTC at 6:1 Comp 19° BTC at 7:1 Comp	Fixed at 13° BTC
Air intake humidity	25-50 grains of water vapour per lb of dry air	25-50 grains of water vapour per lb of dry air
Mixture temp	300°F	Uncontrolled but generally approx 90°F
Mixture strength	That for max knock	That for max knock

Factors Affecting Automobile Octane Number Requirements

As previously stated, the primary object of determining the knock rating of a fuel in the laboratory is to predict its behaviour on the road. There can, however, be no permanent solution to this problem as engine design is constantly changing no less than methods of fuel manufacture. For these reasons the problem of specifying laboratory octane numbers of commercial fuels which will satisfy a particular car or group of cars is one of considerable difficulty and must be kept constantly under review.

There are also other variables which affect the fuel requirements of cars and which may also affect the fuel rating in a given car. Some of these may cause wide variations in fuel requirements of engines in a short interval of time.

Of what may be termed engine

variables, the ignition system may be one of the worst offenders. Spark timing is usually determined by an automatic mechanism which advances the timing as the engine speed increases and in some cases also varies the timing with the pressure in the induction manifold, which depends on the degree of throttle opening and engine speed. Slight variations in manufacture of this mechanism, the effects of wear, or lack of proper lubrication may cause variations in performance and in the anti-knock quality of the fuel required to ensure knock-free operation. If, moreover, the moving parts do not work quite freely the actual spark timing at a given engine speed may be quite different when accelerating and decelerating. Continually changing engine conditions also may have pronounced effects on requirements as in the course of time between overhauls some degree of deterioration is experienced. An overheated plug or exhaust valve, due to bad seating, can raise the octane number requirements considerably. Wear and sticking of rings and general cylinder wear may reduce engine compression but this may not lead to reduced detonation, as throttle opening is increased to maintain power. Excessive oil leaks past the piston into the combustion space may also be a source of increasing detonation as such oil is largely burnt with the petrol. The accumulation of carbon in the combustion space is an important factor difficult to evaluate with any degree of precision. The octane number requirement of an engine generally increases rapidly with mileage for the first two or three thousand miles, and subsequently generally rises more slowly, or in some cases hardly at all. This is probably due to the carbon being burned away as rapidly as it forms and after a certain period ceasing to increase.

Atmospheric conditions, too, have an influence on engine requirements and the effects of temperature, humidity, and barometric pressure must be allowed for if comparable results are to be obtained over a period of time. The tendency to detonate increases with increasing barometric pressure or increasing temperature and decreases with increasing humidity. The magnitudes of these effects are fairly well established and although they may vary somewhat from car to car, corrections can be made to determine octane number requirements which will be reasonably accurate on an average basis.

The object of such corrections is to make allowance for the most severe atmospheric conditions which are likely to be encountered for any significant period of time, and which can generally be determined for a given locality from official records.

These conditions will generally be those obtaining during the warmest period of the year with a high barometer and a relatively low degree of humidity. It has been found that octane requirements determined at low temperatures under humid conditions in the winter may have to be corrected by as much as plus 3 to 4 octane numbers or more to make allowance for the most severe summer conditions of temperature and humidity.

Road Test Methods and Correlation between Laboratory and Road Ratings

Road tests are generally made to determine the anti-knock quality necessary to ensure knock-free operation of the vehicle concerned or for the purpose of measuring the octane number of a fuel or series of fuels in the particular car or cars concerned. The octane rating of a fuel in a car is its "Road octane number" and is equivalent to the percentage of octane in heptane which in the same vehicles and under the same conditions knocks to the same degree as the fuel concerned.

Octane Number Requirement

The octane number requirement of a

car or series of cars is generally determined in order to specify the laboratory octane number of commercial fuels which will satisfy such cars under all normal conditions of driving. Such information may be required so as to estimate what proportion of the cars in use in a given market area will be satisfied by a given octane number.

Owing to the variables previously mentioned, it is necessary in such an investigation to test a fairly large number of cars, to ensure that a representative cross-section of the car population is obtained. The test procedure used should simulate the most arduous conditions of driving from the point of view of tendency to detonate, and such conditions most frequently correspond to operation at full throttle in top gear at low road speed although it is sometimes found that maximum knock is encountered at relatively high speed.

For such tests therefore the car is generally driven, after being warmed up to equilibrium conditions, between 10 or 15 m.p.h. and say 50 m.p.h. in top gear with full throttle to determine the octane level fuel required to ensure that no more than a trace of detonation is encountered at any point throughout the speed range.

If this is done, using blends of octane and heptane and also blends of commercial fuels of known Motor and Research octane number similar in composition to the fuels which it is proposed to market, the requirements of the market are ascertained.

Road Rating of Fuels

The type of test described for the determination of the octane number requirements of cars or of the road octane number rating of a commercial-type fuel takes no note of the speed at which maximum knock occurs. It determines only the lowest octane number which will satisfy a car under any normal conditions of driving or the road octane number of a fuel irrespective of the speed at which maximum knock occurs.

It will almost certainly be found in such tests that whereas a given blend of simulated commercial fuels may just satisfy several cars, the same cars will not be satisfied by the same blend of primary reference fuels octane and heptane. In other words the road octane number of the commercial fuel in question will not be constant in the various cars.

It has been found as the result of a very large number of tests that the road octane number of commercial fuels varies considerably in different cars. It is generally found however that the road octane number of a fuel is somewhere between its Motor and Research rating. These tests have also shown that the mean of these ratings of a fuel is, on the average, the best indication of its road octane number.

The simple procedure described may also be used to determine the road octane number of a series of fuels in the same car. In such tests, if the ignition is set to the maker's standard, heavy knock may be experienced on some fuels and very little or none on others. A common method of overcoming the difficulty of assessing a wide range of knock intensities is so to adjust the ignition setting on each fuel that no more than an agreed standard of light knock is produced.

It is permissible so to vary the ignition only over a fairly narrow range, however, so that the performance of the car as measured by the time required to accelerate between say the speeds of 20-50 m.p.h. in top gear does not fall off from the optimum performance obtainable by more than say 5 per cent.

This means that fuels of a certain octane number range only can be tested in a given car unless radical alterations are made, such as adjustment of the compression ratio.

It is often desired to obtain a more

comprehensive picture of the behaviour of a fuel on the road than can be determined by the simple procedure described and such data may be of great interest to the fuel manufacturers.

Various procedures may be used to obtain such information but the one described has proved satisfactory in practice. It determines the actual octane requirement of a car at any point in the whole speed range at full throttle or the actual octane number of a fuel at any speed in the range.

The test course is a hill of substantially constant gradient and of sufficient severity to ensure that when approached at speeds up to 60 m.p.h. in top gear on full throttle the car speed will be considerably reduced. If sufficient reduction in speed cannot be obtained in consequence of the natural gradient, extra vehicle loading or braking must be used.

For the purposes of the test the ignition automatic advance mechanism is locked out of action and the vacuum ignition control disconnected.

Testing of a fuel is conducted in successive stages of decreasing ignition advance. Ignition settings above 50° early are not used as this in nearly all cases is well above the conditions of practical operation. Assuming that the fuel to be tested is of a high octane number an ignition advance of 50° early may first be tried. From the starting point A the car is accelerated through the gears to pass a point B at the commencement of the hill at the highest speed in top gear at which it is desired to rate the fuel. At this point the throttle is fully opened and as the car is decelerated by the gradient the observer notes the speed at which knocking commences. The initial ignition setting aimed at is that which will cause detonation to come in at about 5 m.p.h. below the speed at point B and the setting may have to be adjusted to achieve this. Having obtained the first point on the fuel rating curve the

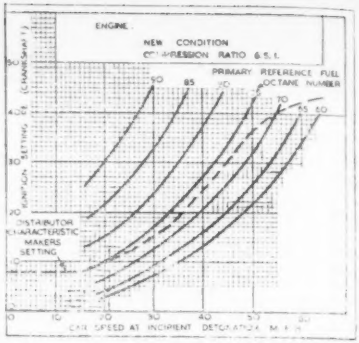


Fig. 1. Typical incipient knock framework.

procedure is repeated with the ignition retarded 5°, the car then being operated to pass the point B at a speed equal to that at which detonation came in on the previous run. Successive runs at progressively retarded ignition settings will result in a series of points forming a curve relating ignition advance for incipient detonation and speed over the desired speed range say between 20-50 m.p.h. A series of octane/heptane blends are tested in the same manner to obtain a framework of curves bracketing the test fuel over the entire speed range and by superimposing the curve obtained with the test fuel on the framework of curves obtained with the reference fuel blends, the octane number of the fuel at any speed can be interpolated.

Fig. 1 is a typical framework of incipient knock curves obtained in this manner together with the curve obtained on a fuel being tested, and shows how the octane number of the fuel varies with speed.

Superimposed on this framework of curves is a curve showing the normal ignition advance obtaining over the speed range when the automatic advance mechanism is in operation and this curve indicates the octane requirement of the car over the whole speed range.

THE FESTIVAL OF BRITAIN

The theme of the Festival of Britain is to tell the story of the contributions which British advances in science, technology, industry, and design have made to civilization. Both in the South Bank Exhibition and in the Exhibition of Science at South Kensington that story is told in a fascinating and entrancing manner and science and technology are made simple by the skill of the designer.

The petroleum technologist must not expect to find much about his own industry as such, for petroleum in material quantity is not an indigenous product of Britain. While it is true that petroleum refining and the newer petroleum chemicals industry are rapidly becoming of still greater importance in the industry and economics of Britain, it has obviously not been possible to find room to illustrate every facet of the basic industries such as chemical engineering. It should have been recognized, however, that James Young did in effect initiate the petroleum refining industry of the world by his work in Scotland a century ago.

Nevertheless, the visitor to the exhibitions, whether he be scientist, technician, or layman, will find much to interest him and can hardly fail to learn some new facts about other industries and even perhaps about his own.

South Bank

In a comparatively small area of 27½ acres on the south bank of the Thames is the centrepiece of the Festival—the South Bank Exhibition. This, it is pointed out, is not a museum or a trade show—it is a story of which each pavilion is a chapter, illustrating the past, the present, and a preview of the future.

Here it is possible to deal briefly with only those pavilions which may be of special appeal to the petroleum man, but the visitor would be well advised to follow the route suggested in the official guide.

Thus, in the Dome of Discovery, it is shown how science and technology have provided the tools and methods for exploration and development of overseas territories. Science has revealed the structure of the earth and technology develops the natural resources. Likewise, the application of science and technology to the sea, to astronomy and weather forecasting, and to the physical and living worlds is demonstrated in an easily-understandable manner.

The Minerals of the Island pavilion is devoted entirely to coal and steel, while in the Power and Production building are shown the high-lights of modern machinery for such diverse purposes as paper or biscuit manufacture. In the Sea and Ships exhibit the use of the diesel as a propulsion unit is exemplified and a model of the stern of a tanker serves to stress the importance of these vessels to British shipbuilding. The internal combustion engine—gasoline, diesel, or gas turbine—is particularly evident in the Transport exhibit and there are some fine diesel-electric locomotives on show.

There are at least fifteen other pavilions in the South Bank Exhibition which should not be missed.

Exhibition of Science

In distinction to the South Bank and other displays where science and technology are illustrated in relation to contemporary life, the exhibition at South Kensington has the theme of the growth of knowledge of matter.

Although planned primarily for the visitor with no scientific knowledge, there is much which will interest the specialist. Entering the exhibition, the visitor is led through a series of displays where the graphite of a lead pencil is progressively enlarged to 10,000 million

times its natural size. Following this the exhibition in the main hall proceeds along three main lines: (*a*) the physical and chemical nature of matter: (*b*) the structure of living things: and (*c*) projects on which work is at present in progress.

For the mathematical-minded visitor there is an added attraction in the Ferranti Nimrod Digital Computor, and he can match his skill against this "electronic" machine in the game of Nim. The machine can be beaten.

Film Shows

A series of programmes of scientific films from British and Commonwealth sources is taking place in the South Kensington Science Exhibition Cinema. Programmes, which start at 1 p.m. daily and continue at hourly intervals are free of charge to those who have paid to enter the exhibition.

Films being shown include "A Hydrocarbon Story," presented by Shell and specially compiled for the Festival of Britain.

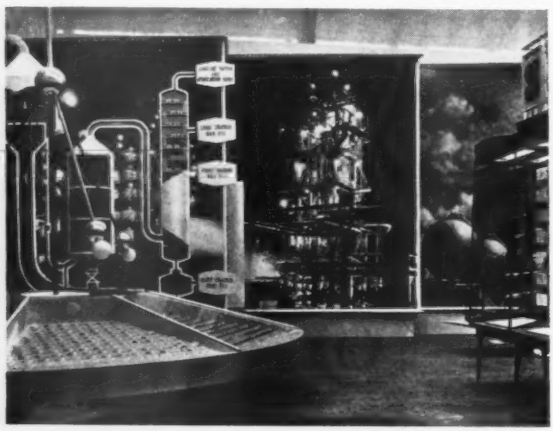
B.I.F., 1951

Principal petroleum exhibit at the Olympia section of the 1951 British Industries Fair was the joint stand of Shell Chemical Manufacturing Co. Ltd. and "Shell" Refining and Marketing Co. Ltd. Here were displayed samples of the 458 petroleum products and an ingenious illustration of the cracking of gas oil. In a large photograph of a cracking column three cinema screens had been inserted. On the screens were seen ascending vapours and by means of molecular diagrams it was shown how these were changed in type and structure as they travelled up the column.

Petroleum-based chemicals and solvents were exhibited on the joint stand of the British Petroleum Chemicals Ltd., British Industrial Solvents Ltd., and the Distillers Co. Ltd.

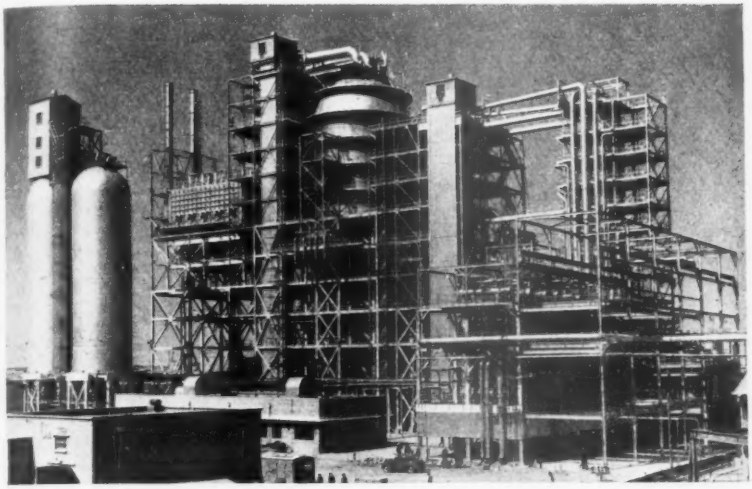
Solvents, plasticizers, detergents, and lubricant additives were on view on the stand of Monsanto Chemicals Ltd., and the use of Fullers' earth in oil refining and regeneration and for well drilling was featured on the exhibit of The Fullers' Earth Union Ltd.

In the scientific section there were several exhibits of some interest to the petroleum industry. These related particularly to petroleum testing apparatus shown by H. J. Elliott Ltd., W. & J. George & Becker Ltd., Glass Developments Ltd., Poulten, Selfe & Lee Ltd., and The Tintometer Ltd.



Shell stand at the B.I.F.

ABADAN CAT CRACKER



An output of 340,000 gallons of motor spirit and other products will be possible from Anglo-Iranian's new catalytic cracker and gas recovery plant at Abadan.

The unit will take 850,000 gallons of waxy distillate from 18,000,000 gallons of crude oil daily processed in the refinery.

Something like 50 per cent of the cat cracker output will go through the gas plant and come out as fuel gas, butane/butene (for use in the alkylation process) and gasoline.

The rest of the cracker's output is light and heavy gas oils and clarified oil.

The cat cracker has been designed for two operations, one of which is to take 25,000 barrels of oil a day at a light product conversion rate of 55 per cent, and the other to cope with 29,000 barrels at a conversion rate of 45 per cent. It is hoped that the input will be increased eventually to 35,000 barrels a day.

Into the two plants and two additional boilers and link-up lines, went 13,500 tons of steel and 1,700 tons of cement. The cracking plant covers an area of 235 feet by 275 feet and is 175 feet in height, having 13 floors, which are served by two lifts.

Fifteen miles of piping, 10,000 feet of which are of stainless steel and 1,000 feet of eight-inch chrome steel, were used.

The regenerator measures 47 feet in diameter and is one of the world's largest. One of the catalyst carrying lines is nearly eight feet in diameter.

The two catalyst storage hoppers have a capacity of 1,500 tons, and one is designed to take a temperature variation from atmosphere to 1,000 F in a few minutes. This would come into use to take the catalyst should it be necessary to shut down the plant in an emergency.

The gas recovery plant has a capacity of 21,000,000 cu. ft. per stream day and eight compressors with a total horse power of 3,000.

PETROLEUM IN PARLIAMENT

Lube Oil Testing

The Minister of Supply was asked on April 23 when adequate facilities for the type testing of lubricating oils and hydraulic system fluids for vehicles and aircraft would be available in the U.K. so that no British oils for Government tenders would require to have been previously approved by an analyst of the United States Government.

Mr G. R. Strauss, in a written reply, said: We have planned to equip a Ministry of Supply test house, but, owing to the difficulties of obtaining the necessary equipment, I am not optimistic that it will be ready under two years. With the considerable facilities already existing in industry, this should make the United Kingdom almost, if not quite, self-sufficient.

Oil Reserves

Asked whether there were in reserve adequate stocks of oil for the Royal Navy and whether the storage depots at home and overseas were adequately dispersed and protected against modern forms of air attack and the possibility of sabotage, the Civil Lord of the Admiralty said (April 25): As stated in the recent debate on the Navy Estimates, provision is being made for stockpiling of oil, and all possible measures are being taken to bring reserves up to the level required under the re-armament programme. Projects are in hand for providing increased storage accommodation and for giving additional protection to oil storage from all forms of enemy activity.

Further asked whether modern methods, such as under-water storage, were being considered as being more adequate methods of protection than those adopted in the past, Mr Edwards said that the matter was also under active consideration.

Petroleum Imports

On April 26 the Minister of Fuel and Power was asked the sources of U.K. crude petroleum imports in 1929 and in 1950 and the refineries from which refined petroleum imports emanated.

In a written reply the Minister said: The sources of crude petroleum imported into the United Kingdom in 1929 and 1950 were as follows :

Thousand statute tons

	1929	1950
Iran	1,359	2,383
Other Middle East	—	5,270
Netherlands W. Indies	148	1,093
United States	—	78
Rest of America	439	441
Rest of World	3	58
	1,949	9,323

Information is not available about all the refineries from which refined petroleum products were imported into the United Kingdom. But approximately three-quarters of the total of these imports in 1950 came from the following refineries operated by British or British-Dutch companies: Abadan (Iran); Curacao (Netherlands West Indies); Arend Aruba (Netherlands West Indies); Cardon (Venezuela); Pernis (Netherlands); Point Fortin (Trinidad); Point a Pierre (Trinidad).

International Petroleum Council

The Minister of Fuel and Power was asked on April 30 what steps had been made since September 1945 to set up a permanent International Petroleum Council as envisaged in Article III of the agreement between H.M. Government and the Government of the U.S.A. In a written reply, the Minister said that the agreement had never been ratified by the U.S. Congress.

Russian Fuel Oil

Asked how much fuel oil had been purchased from the U.S.S.R. since

1947, the Minister of Fuel and Power in a written answer in April 30 said: In 1948, a British controlled company bought 9,300 tons of fuel oil from a Russian company; in return, they agreed to supply the same amount to Soviet vessels in the Far East.

Petrol Brand Names

In a written answer on April 30, the Minister of Fuel and Power said he could not say when it would be possible to allow the sale of petrol under brand names and of the higher octane petrols associated with brand names.

★ ★ ★

MINISTER PRAISES LLANDARCY ACHIEVEMENTS

A tribute was paid to R. B. Southall, member of Council, by Mr Alfred Robens, Minister of Labour, at a dinner given by the Industrial Association of Wales and Monmouthshire at Porthcawl on April 20. Mr Robens, who was at the time Parliamentary Secretary, Ministry of Fuel and Power, after speaking of the coal mining industry, and those undertakings which are dependent on it said:

"There is of course another very important fuel and power industry but I left some mention of this until the last because it gives me the opportunity to pay a particular tribute to a man who, though not a Welshman has come to live in Wales to work here and has been mainly responsible for the enormous extensions and management of the huge oil refinery at Llandarcy, namely my good friend and your President elect (of the Industrial Association of Wales and Monmouthshire)—Mr R. B. Southall.

"In 1947 the capacity of this refinery was 360,000 tons a year. By May, 1953, it will have increased to over two million tons a year. This is a great achievement. The credit is due to the oil company, but particularly, I think, to Mr Southall who has lived with this job day in and day out through these past years. This will not only provide employment for the 2,000 workpeople at the refinery and more employment at the Swansea Docks where the oil will be brought in and stored, but it will be a very great dollar saver because it will produce more lubricating oil. As we spend proportionately more dollars on lubricating oil than on any other petroleum product this will be a great national asset."

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INCREASED PRICES OF PETROLEUM PRODUCTS

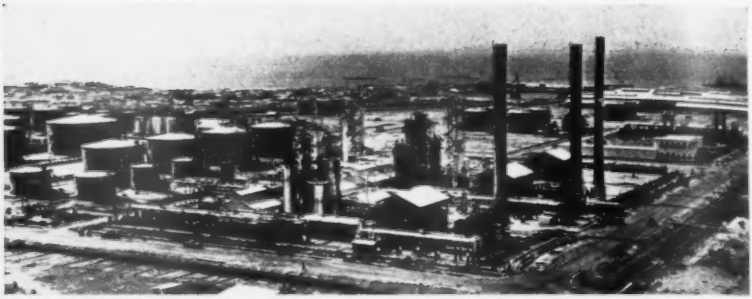
New maximum prices for the main petroleum products in the U.K. were announced by the Ministry of Fuel and Power on May 1st.

The following table, which unless otherwise stated relates to *bulk* deliveries, gives prices in the inner delivery zones. Deliveries in the outer zones (i.e. farther from the main importing centres) are ¼d per gallon higher, and in the general zones (i.e. farthest from the main importing centres) ½d per gallon higher.

	Max. Price per gal.
Motor spirit (bulk)	3/2¾d
Motor spirit (ex-pump)	3/6½d
Diesel oil for road vehicles (Derv.)	3/0⅞d
White spirit (London Zone)	3/5⅝d
Kerosine:	
Burning oil, paraffin oil—	
Ordinary grade	1/3d
Superior grade	1/4½d
Vaporizing oil	1/3¾d
Gas oil: (Diesel oil)	1/1¾d
Fuel oil	10¾d
Heavy fuel oil	10⅜d
Aviation spirit (100 octane)	3/9¾d

Bitumen Prices. An increase effective from May 1 of 15s and 17s 6d a ton respectively in the bulk and packed prices of all grades of Mexphalte incorporating penetration bitumens, oxidized bitumens and hard bitumens, and of ¾d a gallon in all prices of Shelphalt and cut back bitumens, was announced by Shell-Mex and B.P.

NEW FACILITIES AT CARDON



A general view of the refinery at Cardon. The refinery industrial area and residential section occupy an area of more than 3000 acres. [Shell photo.

The capacity of Cardon refinery, Northern Venezuela, now running at 3½ million tons a year, is to be doubled by 1952. Work on the additional facilities, comprising a new distillation unit and modifications to the existing distillation unit are soon to begin.

Nearing completion is a modern installation for the production of over 100,000 tons/year of high quality lub oils which will comprise the following units—propane de-asphalting, furfural extraction, M.E.K/benzole de-waxing, clay contacting.

Up to the present, the Cardon project has cost nearly £50 million.

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PETROLEUM TECHNOLOGY 1948

Volume 10 of the Institute of Petroleum's "Annual Reviews of Petroleum Technology" has just been published and covers the progress made in the scientific and technical aspects of the petroleum industry during 1948. In the twenty-two main chapters will be found references and accounts of the leading developments made during the year under review and the book should prove of considerable value to research worker and student and to anyone who desires to have at hand a ready means of tracing the progress of the industry. In its three-hundred-and-fifty pages, there are references to over 2,000 scientific and technical articles and patent specifications published during the year. The price is 27s 6d post free and members of the Institute may obtain one copy at the special price of 22s 6d.

REPRINTS OF PAPERS BY MEMBERS

Institute members who publish papers in specialized, foreign or other journals which would not normally be received by the Library are requested to send reprints of such papers to the Editor, so that they may be summarized for inclusion in the Abstracts section of the Institute's *Journal*.

★ ★ ★

Elliott Journal. The first issue of a periodical review of developments in engineering, with particular reference to the work of Elliott Brothers (London) Ltd., appeared in March. Vol. 1 No. 1 has a foreword by Sir Ben Lockspeiser, K.C.B., F.R.S., Secretary of the D.S.I.R., an illustrated article on "150 Years of Instrument Making" tells the story of the firm since its foundation, and there are eight technical papers. The journal will be published half-yearly from Century Works, Lewisham, London, S.E.13.

GAS TURBINE TECHNOLOGY

Intensive theoretical and practical courses of one, two and three weeks' duration are provided at the School of Gas Turbine Technology at Farnborough, Hants.

Originally set up in 1944 to instruct Dominions Air Force personnel in the application of the gas turbine to aircraft propulsion, the school's activities are now the responsibility of Power Jets (Research and Development) Ltd.

The syllabus includes lectures on basic thermodynamics and theory of design; specialist lectures on the various applications of the gas turbine and its construction, illustrated by sectioned engines of a number of different types both of the shaft power and jet varieties, including centrifugal and axial compressors; test runs on shaft power and jet types of engines; and, on certain aero engine courses, the actual stripping and installation of engines in aircraft.

The programme arranged for the remainder of 1951 comprises the following types of course: Aero engine design (June 24 to July 6; August 19 to 31; November 25 to December 7); Design and application of industrial gas turbines (July 15 to August 3; October 28 to November 16); International course on aero and industrial gas turbines (September 16 to October 5); Practical aero engine course (October 8 to 19).

The design courses on aero engines and gas turbines for industrial purpose are of post-graduate standard and in addition to lectures on component design, they include the running and testing of engines.

The international courses, provided for the benefit of students from overseas, cover in effect the whole field of gas turbine application.

A high standard of academic knowledge is not required for the practical aero engine course.

FAWLEY REFINERY FILMED

That the construction of a great refinery can make a screen story of absorbing interest is conclusively proved by Esso Petroleum's film on Fawley. The first part of this film, covering the period of site clearance up to early building operations, was ready last summer. The second part, which is now ready, carries the story up to the beginning of 1951.

Some truly spectacular feats of construction are shown in the second part. 265-ft derricks are seen at work on the distillation plant. There is the incongruous sight of the 113-ft debutanizer tower—the biggest piece of equipment to arrive in one piece—bowling along the tree-lined Hampshire roads on a 32-wheel trailer. The fitting in place of the cap of the cat-cracker appears to be a particularly delicate piece of adjustment. As it is lowered from the sky the commentator remarks that at Fawley they believe in flying saucers.

There are sequences showing divers at work on the marine terminal and, as a contrast we are shown the planting of young evergreen and deciduous trees, 4,000 of which will eventually form a 100-150 ft belt of green screening the refinery on the landward side.

The film was made by the Public Relations Film Unit of Esso Petroleum Ltd, with Andrew Rice as producer and writer. Duncan Carse, well-known radio actor, voices the excellent and never obstrusive commentary.

* * *

Engineering Codes. A new addition to the I.C.I. Engineering Codes and Regulations series is now available—Group A, Volume 1.4—Railways and Haulages (Design). This, together with previous publications in the series, is available to the public through the Royal Society for the Prevention of Accidents, 52 Grosvenor Gardens, London, S.W.1.

Newport 1951 is the title of an illustrated booklet issued by Monsanto Chemicals Ltd. It describes their new chemical works at Newport, Monmouthshire.

HEAT TRANSFER DISCUSSION

A conference on the important subject of the mechanism of heat transfer and the design of heat transfer apparatus will be held in London from September 11 to 13, 1951. Joint organizers of the Conference are the Institution of Mechanical Engineers and the American Society of Mechanical Engineers. In addition, co-operation is being obtained from 30 societies in Britain, four in the British Commonwealth, and 11 in the U.S.A.

Executive committees have been working in Britain and the U.S.A. and about 90 papers, including some 35 from the U.S.A., have been promised. There will be five half-day sessions, the papers for discussion having been segregated into five main sections in accordance with the fundamental processes involved. The five sessions will, therefore, deal with developments in the last 10 years under the following headings: heat transfer with change of state; heat transfer between fluids and surfaces; conduction in solids and fluids; radiation, instrumentation, measurement techniques, and analogies; special problems. The sixth and final session will be devoted to the discussion of matters not dealt with or not coming within the scope of the technical sessions.

Meetings will be held at the Institution of Mechanical Engineers, and at Caxton Hall. There will also be a conversazione on September 11 and the James Clayton Lecture will be delivered by Prof A. B. Colburn (U.S.A.) on September 12.

Members of the Institute of Petroleum are eligible for membership of the Conference and should apply to the Editor, The Institute of Petroleum, for a preliminary registration form without delay.

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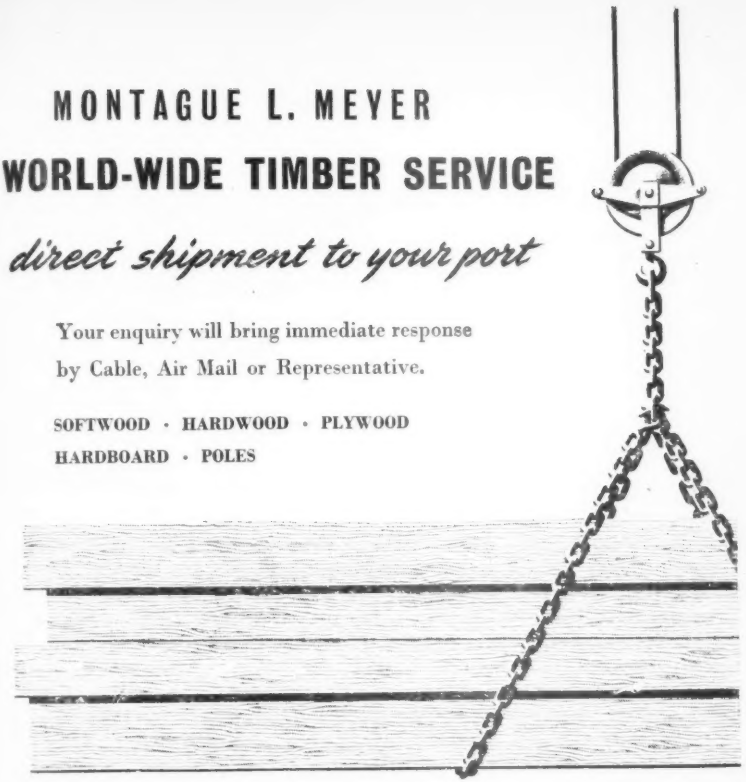

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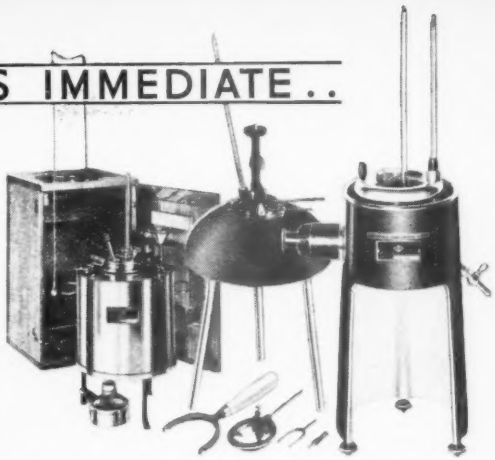

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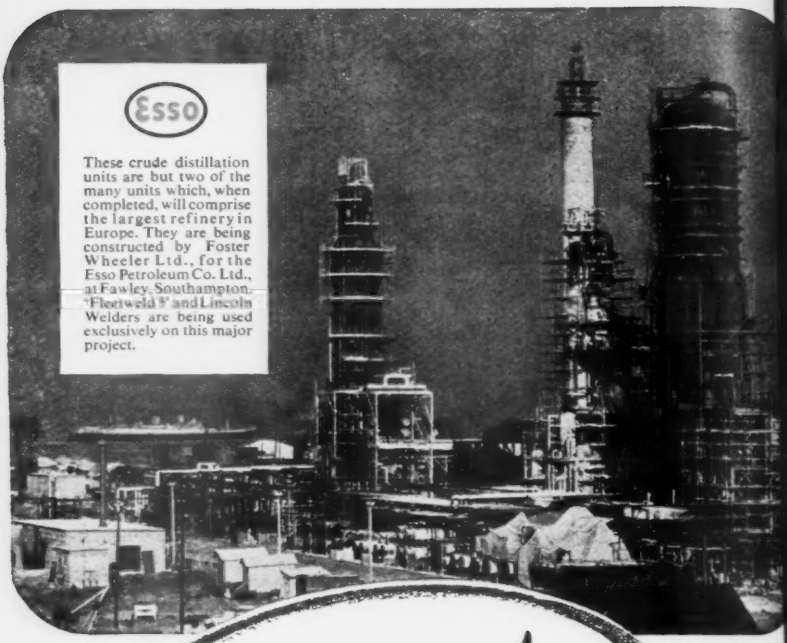
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An Esso photogra
William Marti

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